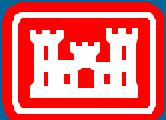


EARTHQUAKE ENGINEERING RESEARCH PROGRAM

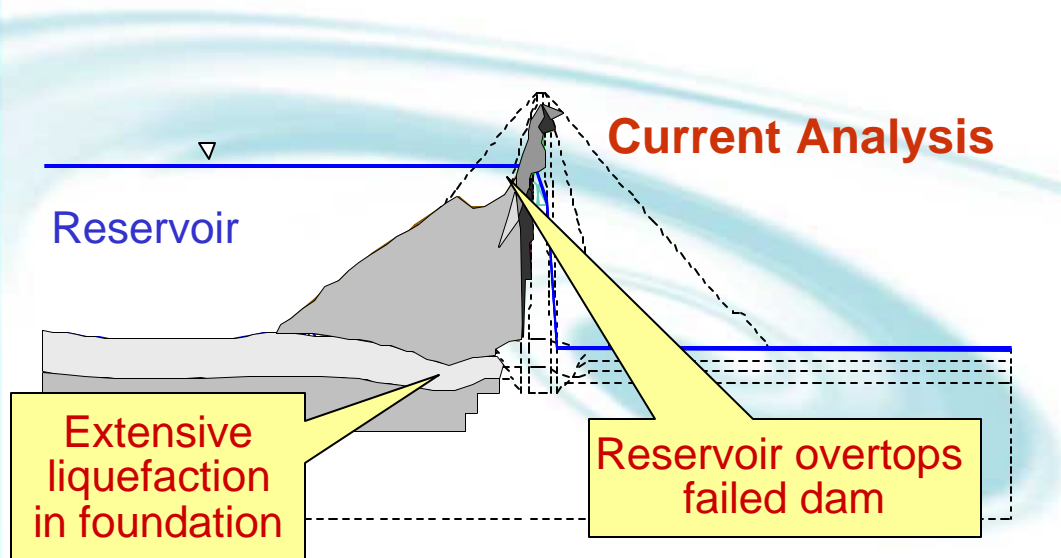
Behavior of Liquefying Soils
& Remedial Measures
Field Review Group

Tuesday, June 19, 2001

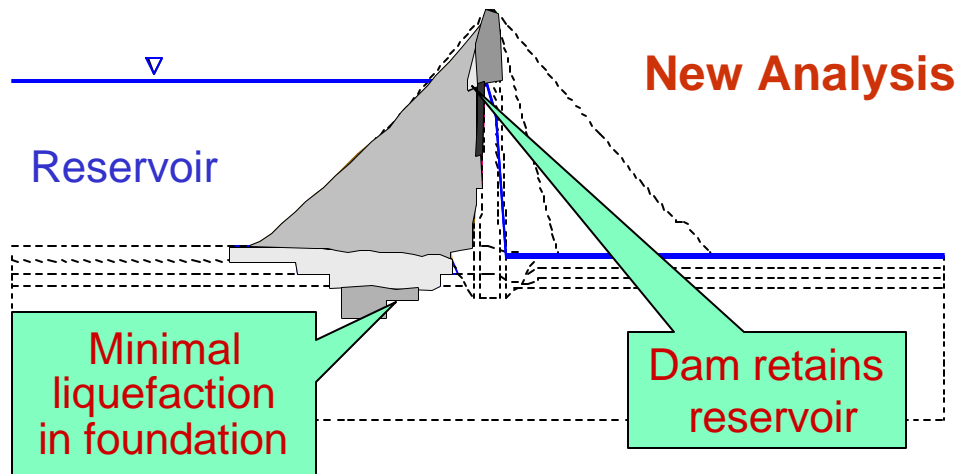


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- Current analysis indicates dam failure
- Remediation costs \$35 Million (Mormon Island Dam)



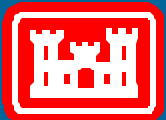
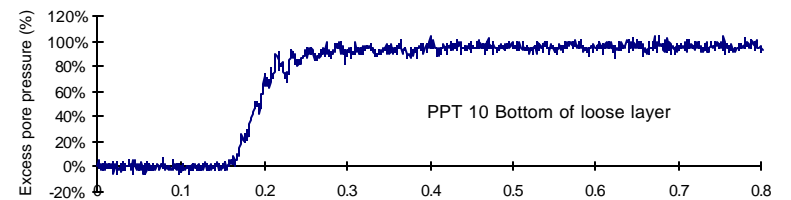
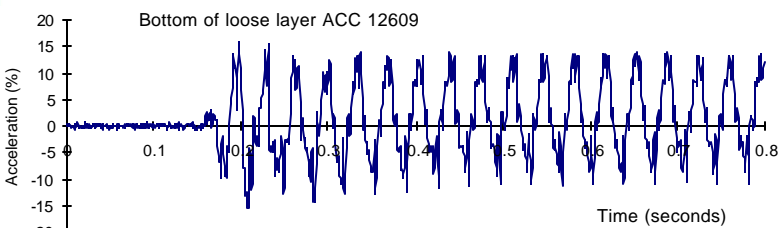
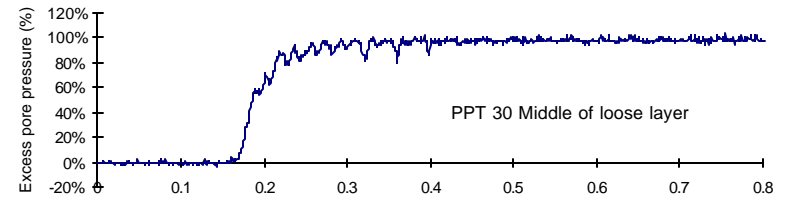
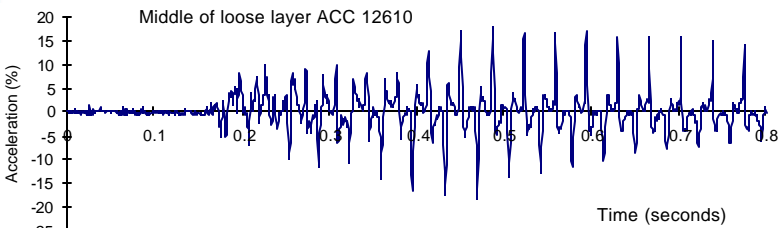
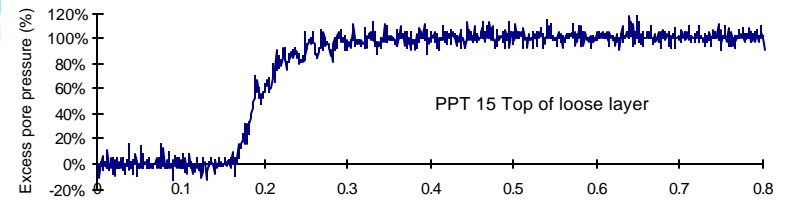
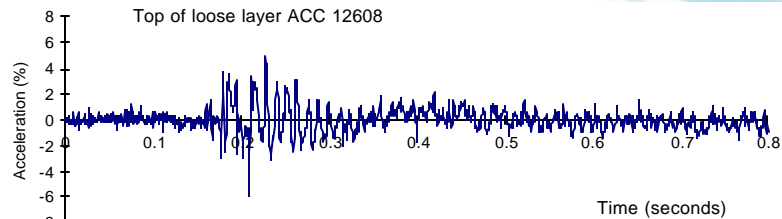
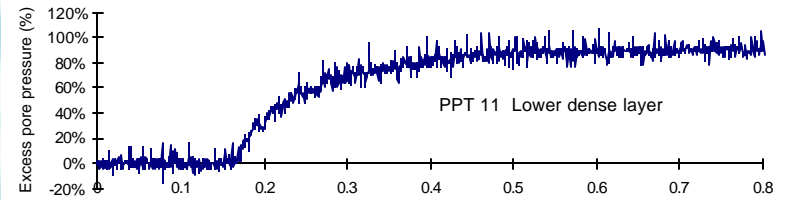
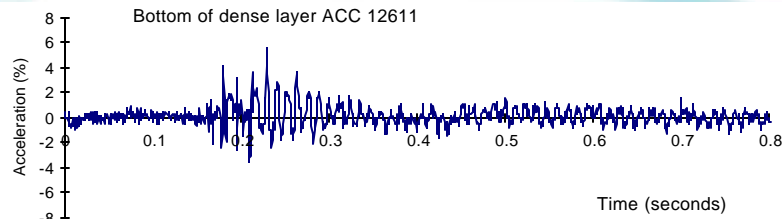
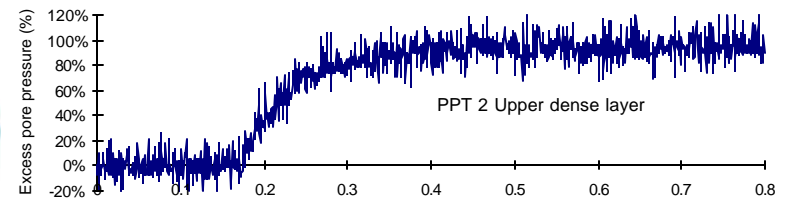
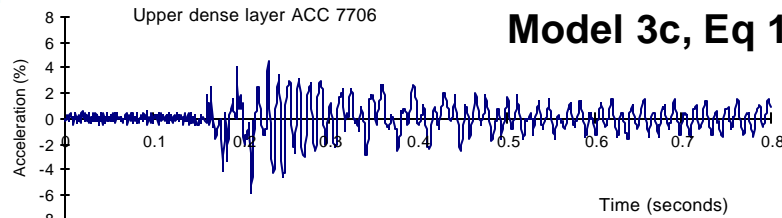
- New analysis indicates minor damage
- Substantial savings in remediation costs, tens of millions



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Model 3c, Eq 1



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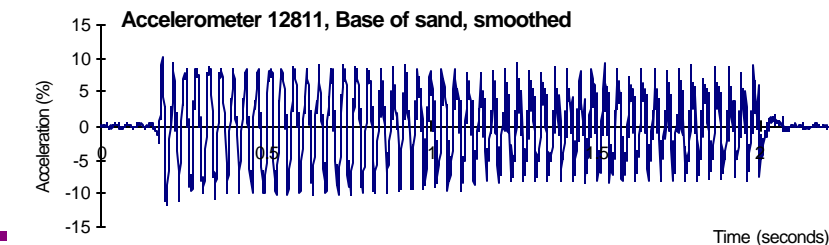
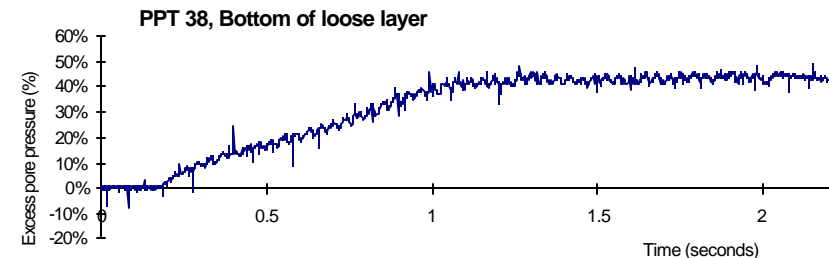
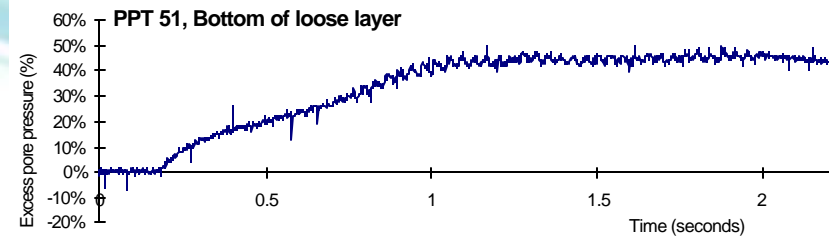
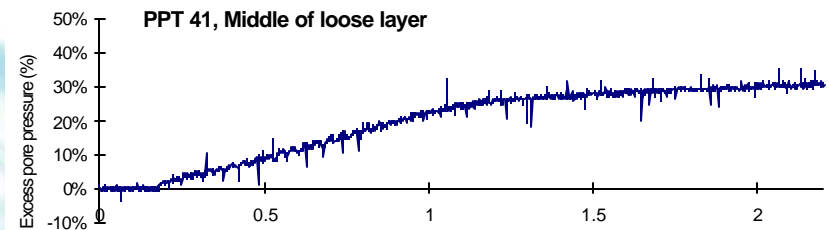
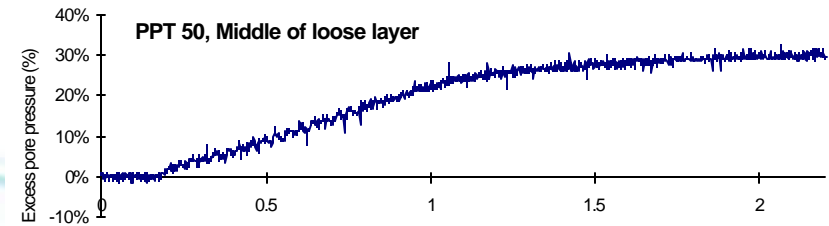
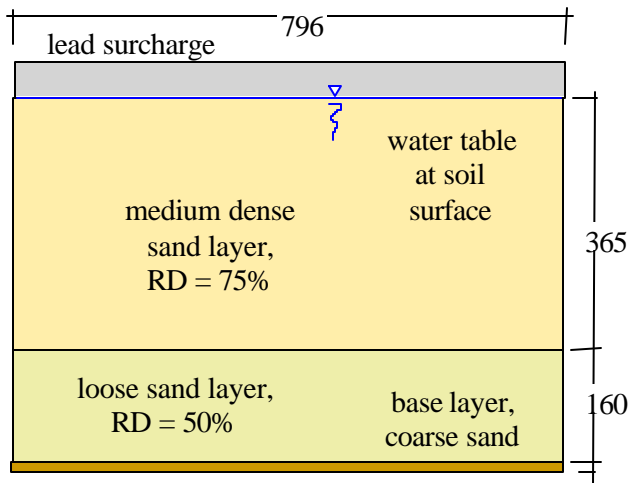
Excess pore pressures in Model 4d, earthquake 2

Middle depth specimen

$$s_v' = 4.7 \text{ tsf}$$

(in the middle of the loose layer)

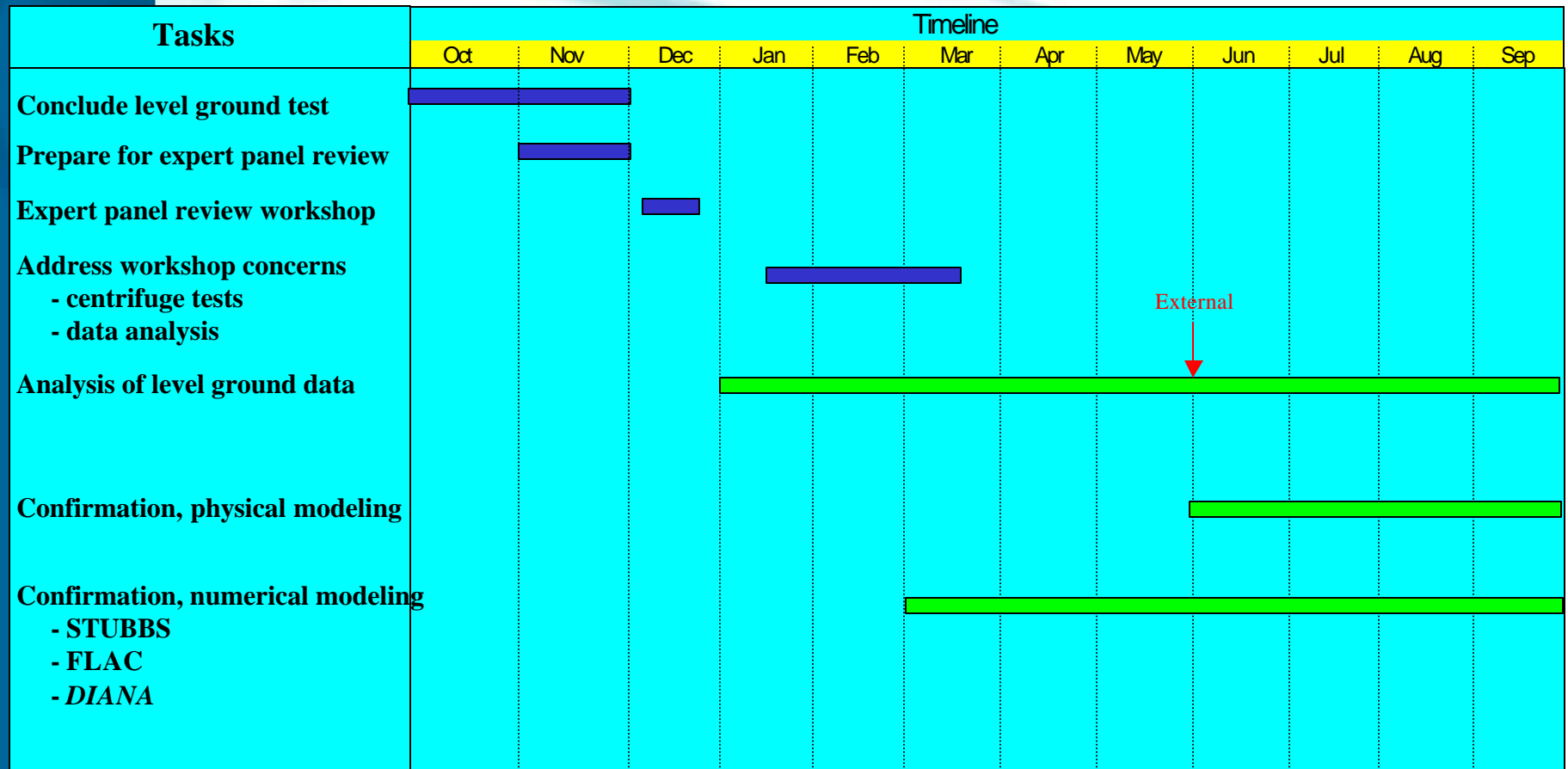
Shows good repeatability
along the length of the
model



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Plan for FY01



Concluded



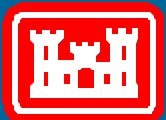
In progress



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Model series	Models in series	Effective overburden stress in loose layer	Depth of equivalent field deposit (approx)	Depth of specimen	Notes (All models used Nevada sand and were tested at 50g unless indicated)
2	a, b, c, d, e, f	1 tsf	15 m	300 mm	
3	a, b, c, d, e	2 tsf	26 m	525 mm	
4	a, b, c, d	3 – 5 tsf	26 – 40 m	525 mm	Lowered water table or lead surcharge
	e, f, g, h, i, j	3.9 – 9.7 tsf	30 – 60 m	525 mm	Light surcharge and change in g level
	k	1.9 – 4.8 tsf	25 – 39 m	525 mm	Change in g level
5	a, b, c, d, e	7 – 10 tsf	54 – 63 m	525 mm	Lead surcharge



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Results of Expert Panel Review

BEHAVIOR OF LIQUIDIFYING SOILS

Technical Specialist Meeting
11 - 13 December 2000

REPORT OF DISCUSSION

Attendees

ERDC Research Team

Dr M.E. Sharp
Dr J.S. Swenson
Dr J.F. Jones
Dr M.E. Hynes
M. W. Smith, ELL
Dr M.J. O'Connor
M.B. Leitch

Invited Technical Specialists

Dr W.P. Mangano
Dr W.B. Ulsay
Professor T.B. Matlock
Dr G. Castro
Dr W.B. Ulsay
Professor P.M. Byrne
Professor S. Kramer
Dr W.B. Ulsay
Dr D.R. Chittas
[E. Hynes and M.E. Sharp]

Background

1) Research into behavior of liquidizing soils is part of a larger research program entitled "Earthquake Engineering Research Program". This program is the only federally funded seismic safety program for dams. This work has been ongoing for the last five years. There have been previous meetings with technical specialists to review the work and progress. In January 1997 and October 1999 there were meetings held with many of the same technical specialists as listed above. From these meetings, many comments and suggestions were given that helped direct the research in this area. At this point, the research is at a crossroads where work related to level ground is completed and that related to sloping ground is about to start. The purpose of the meeting was to review all the data and findings from the level ground work such that all comments and concerns could be addressed before proceeding with further testing. This report documents the comments of the technical specialists and highlights the direction of the ERDC team to address these comments.

Summary of Meeting

2) The meeting lasted for one and a half days during which time the technical specialists were shown the centrifuge facilities and equipment used in the testing, presented the centrifuge test plan and overview of the recorded data, presented the analysis of the data, and shown some of the numerical modeling attempted for the tests. The panel was also given a plan for the proposed future testing in the program.

Technical Specialist Comments

3) The panel agreed that there was a very good, repeatable set of experiments that contained a wealth of data. They also agreed that the finding of a limiting excess pore pressure is clearly shown in the data. The finding of excess pore pressure is a function of the amplitude of shaking (and indirectly the frequency) and depth. One of the primary concerns of the review panel was the amplitude and frequency of input shaking. The data were reanalyzed and two products were a much better input signal with more repeatable amplitude and frequency.

4) One of the biggest concerns of the panel was associated with the testing equipment. Prior to the meeting, Prof. Byrne did some numerical modeling of the centrifuge test with the program FLAC (finite difference program). In that modeling, he discovered that he could only duplicate the results of the centrifuge test (assuming a limiting excess pore pressure at depth) with a horizontal stress in excess of the vertical stress in the direction of shaking. This has been used for testing in the centrifuge. The box is 0.3 m wide by 0.3 m tall. The box is constructed of aluminum rings with very little resistance to expansion in the shear direction. The box is supported during testing by thick walls placed on either side.

There is a rubber membrane placed in the centrifuge with an air duct to allow the box to sit snugly between the walls but still be able to move during shaking. The walls are independent of the shaking platform on which the box sits, and do not move during shaking. After seeing the equipment and discussing Prof. Byrne's findings, the panel was concerned that the box would be partially constrained longitudinally during shaking, and that the box might be expanding laterally. There was a great deal of discussion about this matter. The panel clearly felt that there were some areas that needed to be addressed, or possible reasons for the limiting excess pore pressure scenario.

There was also some discussion about vertical acceleration of the soil and whether in addition to constraining the expansion, which could be checked by measuring the compression wave velocity in the soil. Subsequent to the meeting, Prof. Byrne examined some of the tests and concluded that he could model the results using a coupled stress flow effective stress analysis. He stated that this analysis did not involve any seepage effects, consolidation, or any out-of-phase normal stress. He believes that this model (assuming excess pore pressure) can be explained by flow permeability and bulk modulus of the fluid (consolidation) effects. Prof. Byrne concluded that it is only important to know the compression wave velocity in the box or they cannot both generate and transmit an excess pore pressure.



defined in
or sections
of needed
collocation
from two
each of
of four types
and 2000
me of the
key between
input
cases with
positive and
negative
mean value
cases and
zero value.

the testing
is about the
Prof. Byrne,
and the
the box will
be used to

of the box, and the platform and filling with water. The box will be fully instrumented with LVDTs along the core and to measure lateral expansion of the box. An increase in pore pressure will be accompanied by lowering the g level. The box will give the pressure at which the box begins to expand laterally. Therefore, we can make a direct comparison of the pressure recorded in the model (assuming a worst case) to the pressure that would be recorded in the box. The second test will consist of building a model exactly as we would for one of the centrifuge tests but with more instrumentation on the outside of the box. On the outside of the box, we will instrument with rings with accelerometers. This will allow us to measure the longitudinal response of the box and verify that the expansion is not along the axis of rotation. This model will also have a dense material between the box and restraining wall to measure exactly the amount of lateral expansion in the box during shaking. This model will also have a dense material between the box and restraining wall to measure exactly the amount of lateral expansion in the box during shaking. These two tests will generate excess pore pressure by the panel is maintained in order to generate a net.

Following the comments of some panel members subsequent to the meeting, it is apparent that a different scenario. In this model (concerned exactly with the other centrifuge model) we will instrument to record the compression wave, lateral acceleration response and all needed, and check the acceleration response between the soil and the box. This will address the concerns of the panel regarding the nature of the expansion and contraction of the soil.

They will continue to be, both the data and the data analysis. It is a key question to perform the analysis in conjunction with existing data and to compare with the data. We also plan to continue testing along the lines of that done by Prof. Byrne. A final major item of the data analysis will consist of dynamic response calculations and high and numerical modeling. In Prof. Byrne's case, FEH will use the panel's work. We also intend to have the type modeling performed with other code, utilizing the help of Prof. Byrne and Prof. Hynes. This will address the concerns of the panel regarding the nature of the expansion and contraction of the soil.

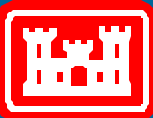
The research team is also very interested in having some of the tests repeated at another centrifuge facility. We feel that the work done to further validate the results being obtained in the ERDC facility. Prof. Byrne at ERL and possibly Prof. Hynes at UC. We will continue with one of the tests.

After the work has been completed, there will most likely be a need for further testing to correct the results and determine direction for the future.

Conclusion

8) On behalf of the ERDC research team, I would like to express our great appreciation for your interest in the research and your time and effort in the meeting. We look forward to many fruitful discussions in the future and will continue to keep you informed of progress.

Michael E. Sharp
Acting Director, Earthquake Research Center
Engineer Research and Development Center



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Results of Expert Panel Review

BEHAVIOR OF LIQUEFYING SOILS

Technical Specialists Meeting

12 – 13 December 2000

REPORT OF MEETING

Attendees:

ERDC Research Team

Dr M.K. Sharp
Dr R.S. Steedman
Dr J.F. Peters
Dr M.E. Hynes
Ms W. Vanadit-Ellis
Dr M.J. O'Connor
Mr R. Ledbetter

Invited Technical Specialists

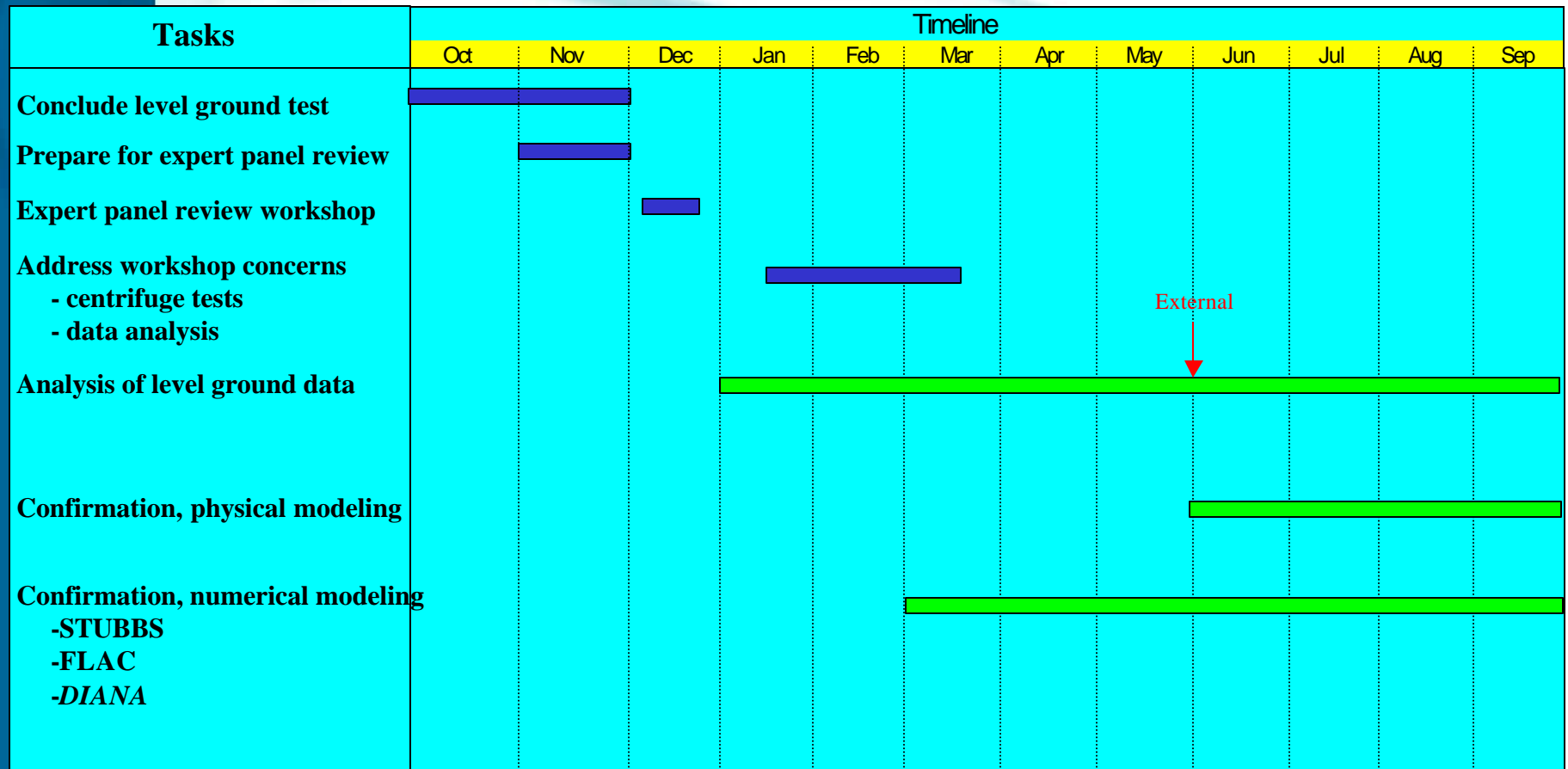
Dr W.F. Marcuson
Professor R. Dobry
Professor J.K. Mitchell
Dr G. Castro
Professor R. Seed
Professor P.M. Byrne
Professor S. Kramer
Professor R. Boulanger
Dr D.R. Gillette
(I. Idriss and W.L. Finn)



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Plan for FY01



Concluded



In progress



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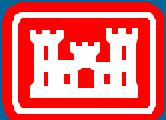
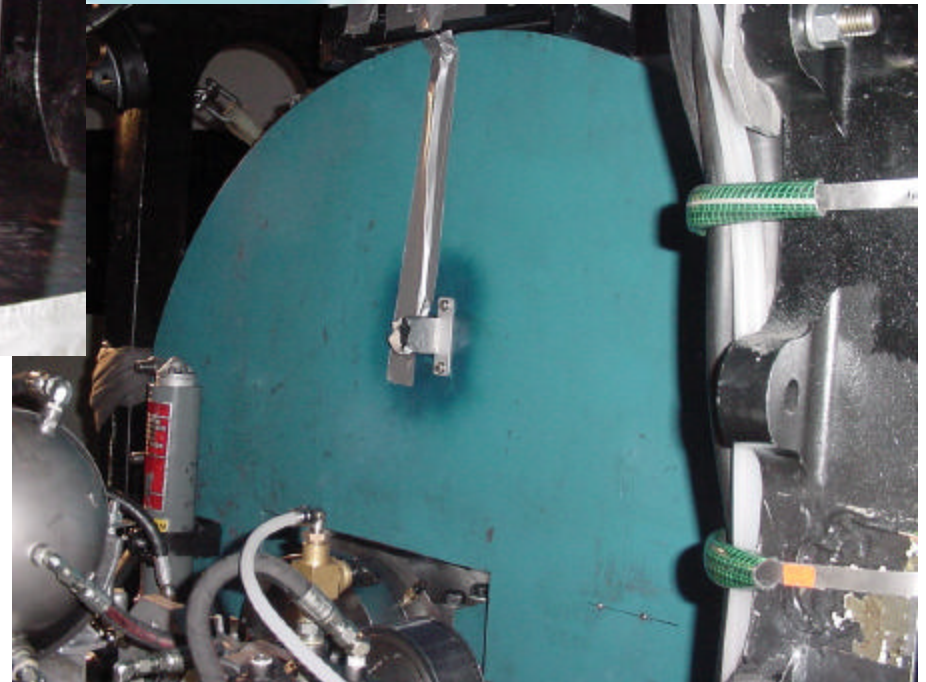
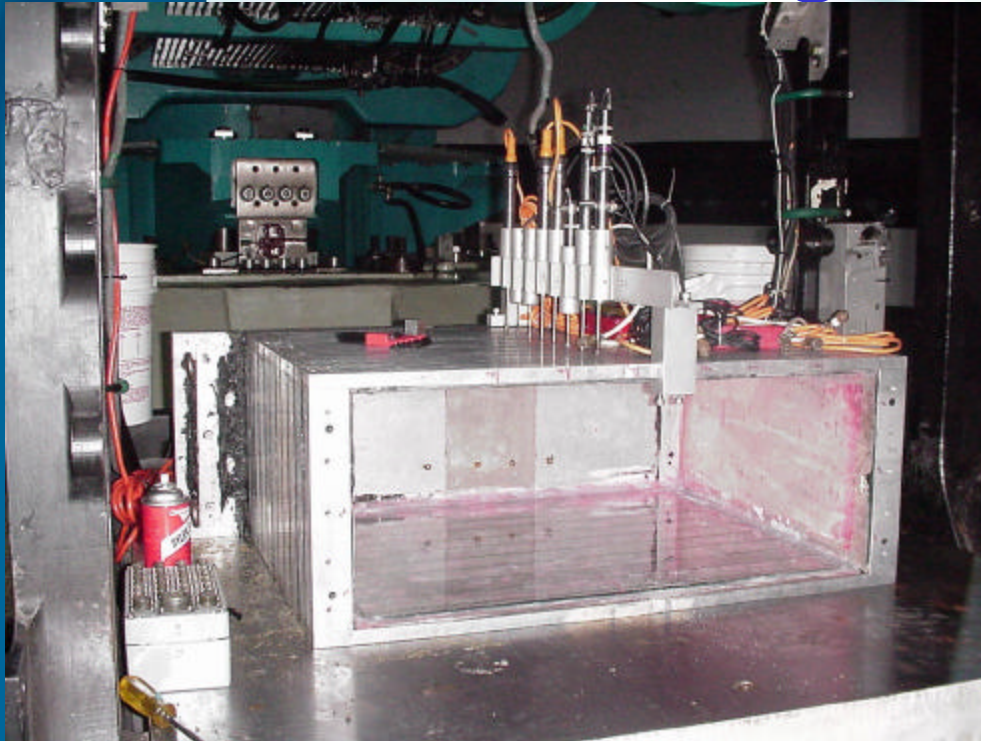
Addressing Workshop Concerns



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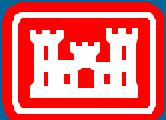
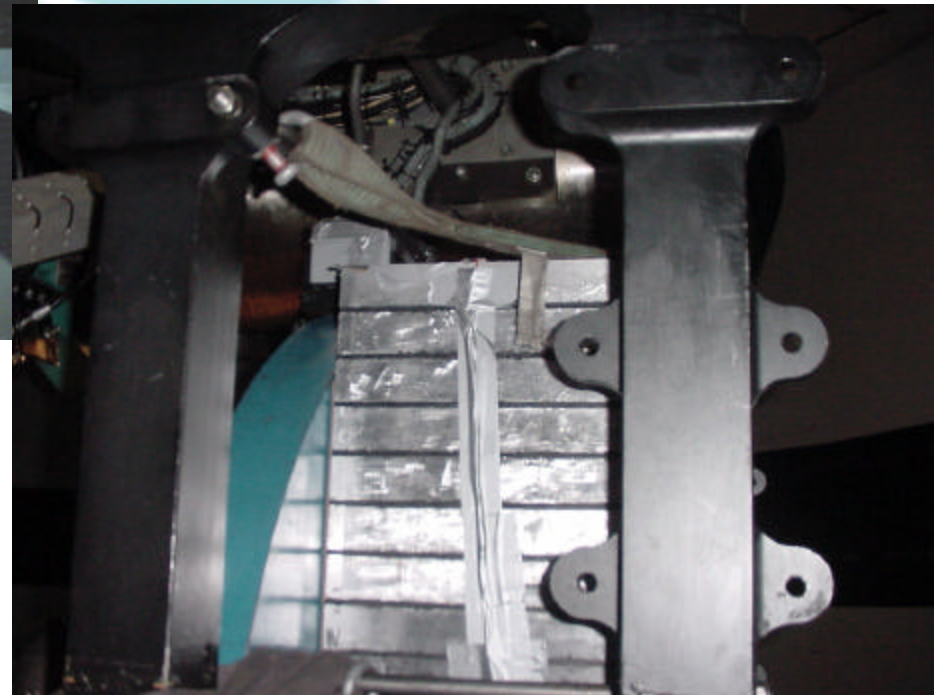
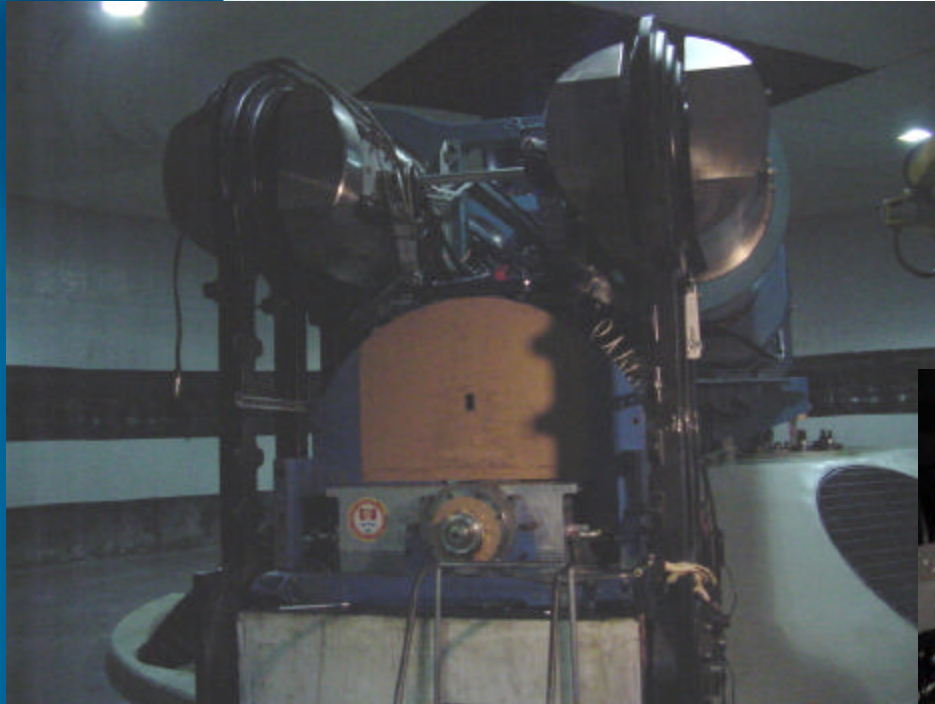
Addressing Workshop Concerns



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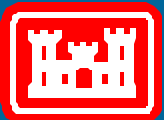
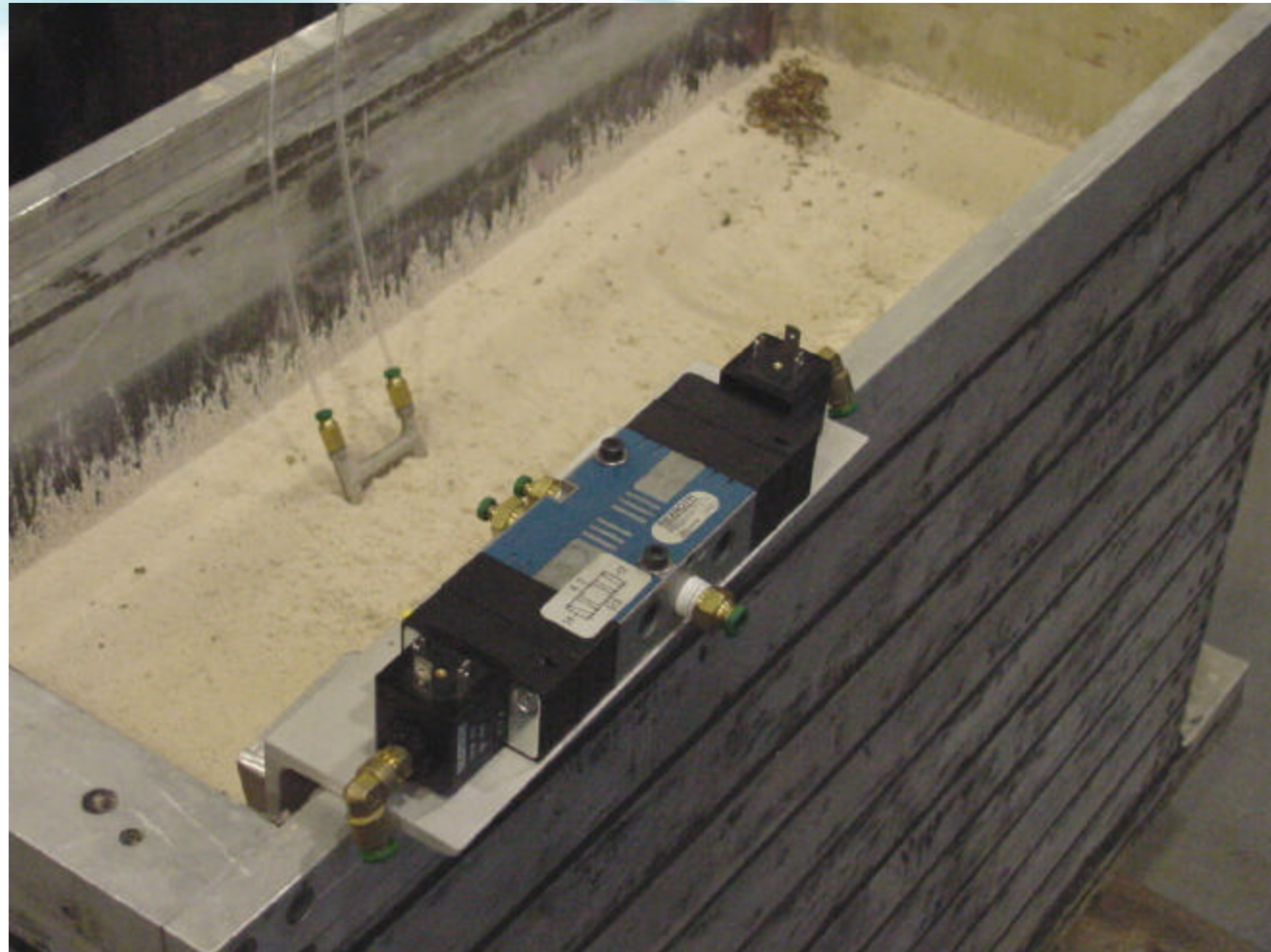
Addressing Workshop Concerns



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Addressing Workshop Concerns

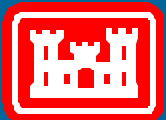


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Additional 'Check' Tests

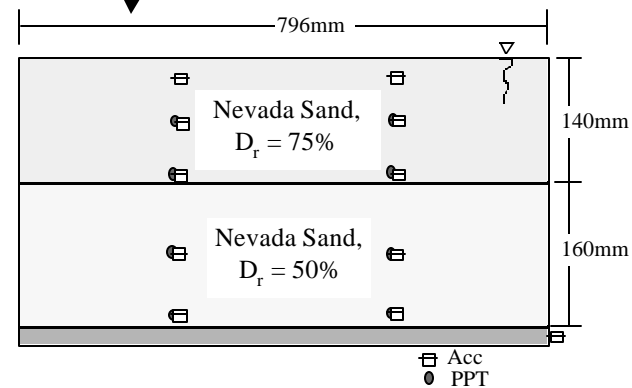
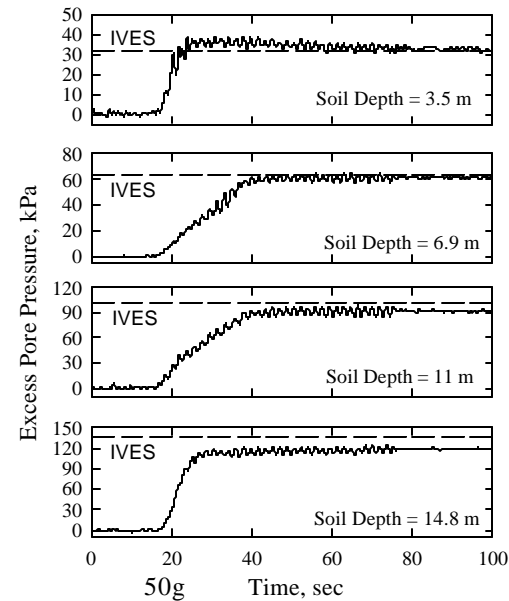
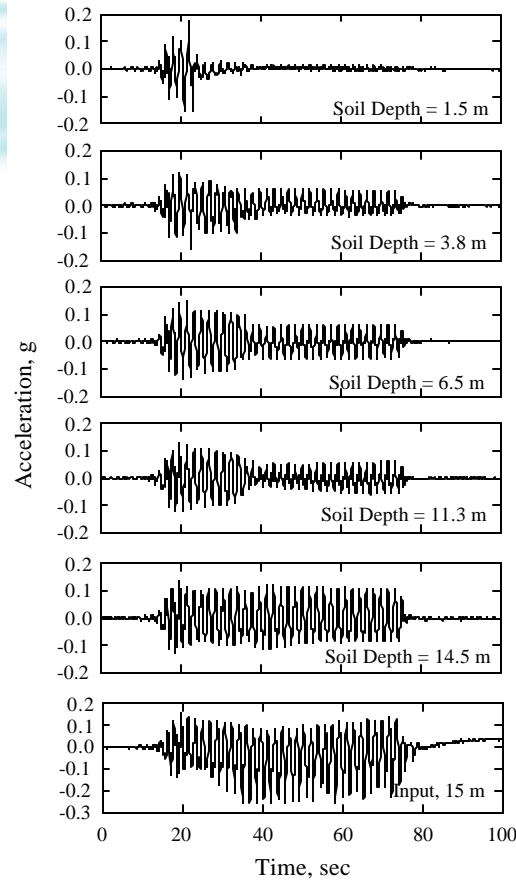
- Model with P/S wave hammer, total pressure cell, and acc's on inside rings
- True model of the models to eliminate concerns about model size
- Clay layer between loose and dense layer



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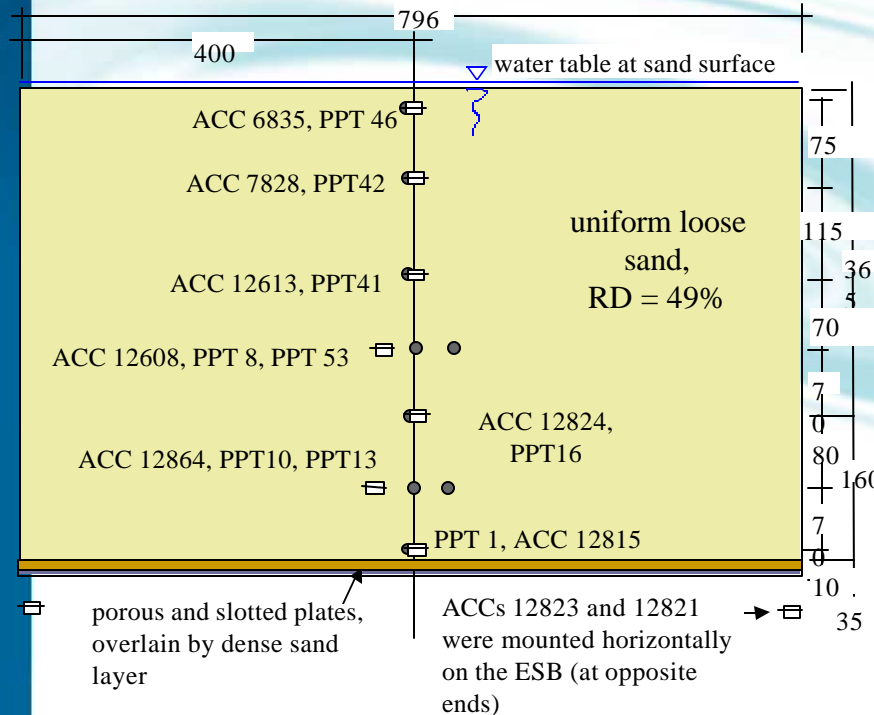
Data Analysis



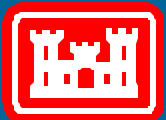
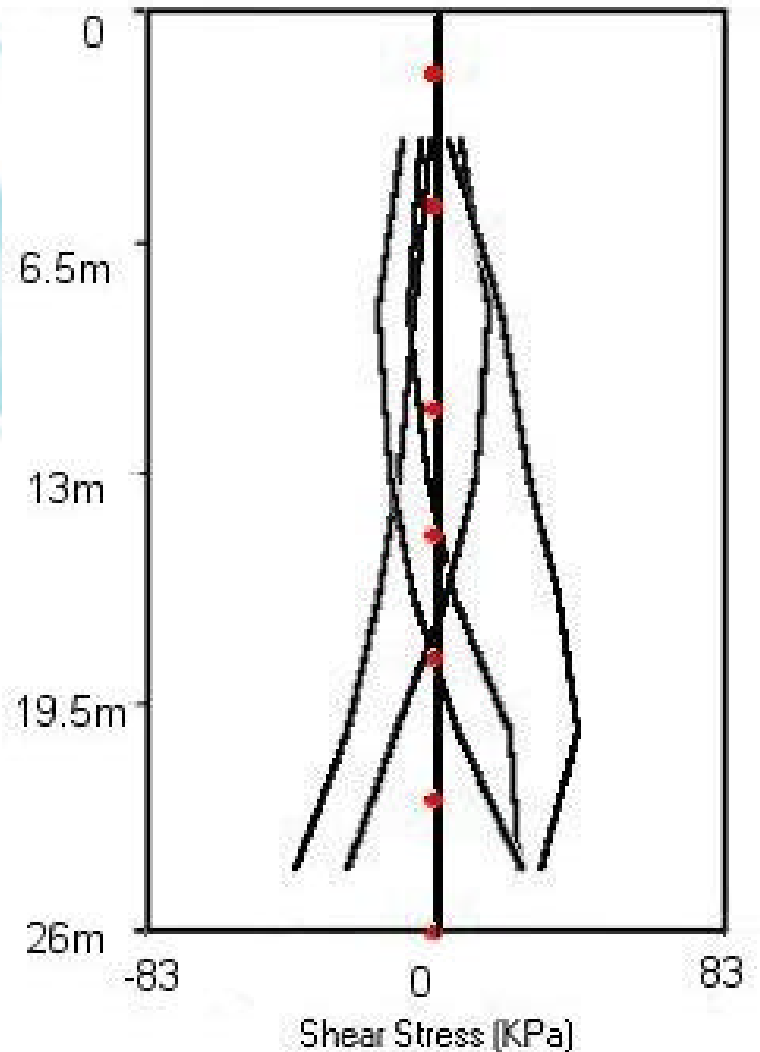
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Data Analysis



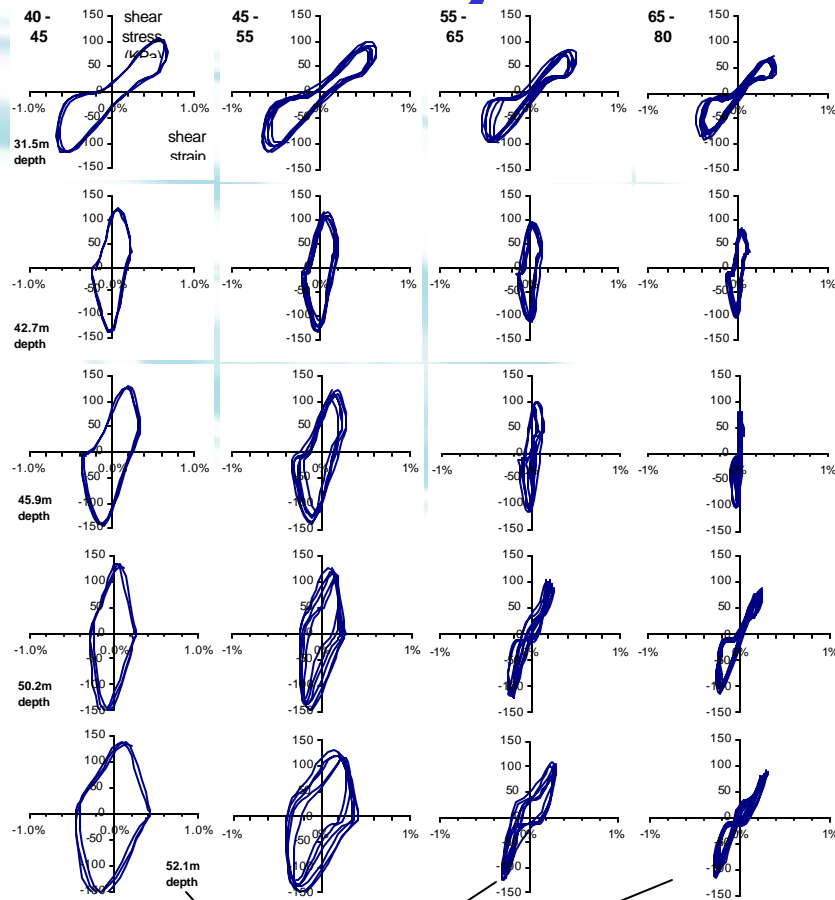
**Animation of shear stress
at different depths**



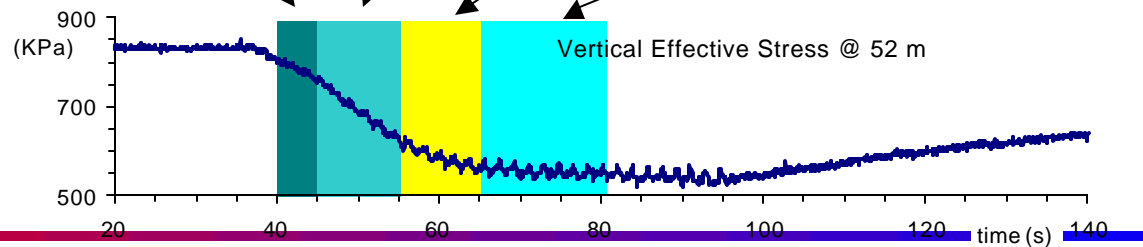
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Data Analysis



Vertical
effective
stress at base
of model

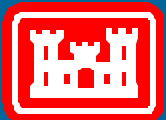


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Additional FY01 Activities

- Independent verification through physical modeling by outside source (3 - 4 models)
- Numerical modeling with FLAC, DIANA, (STUBBS)
- SI analysis



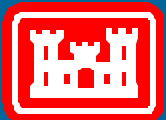
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Technical Plan Overview

FY01- FY04

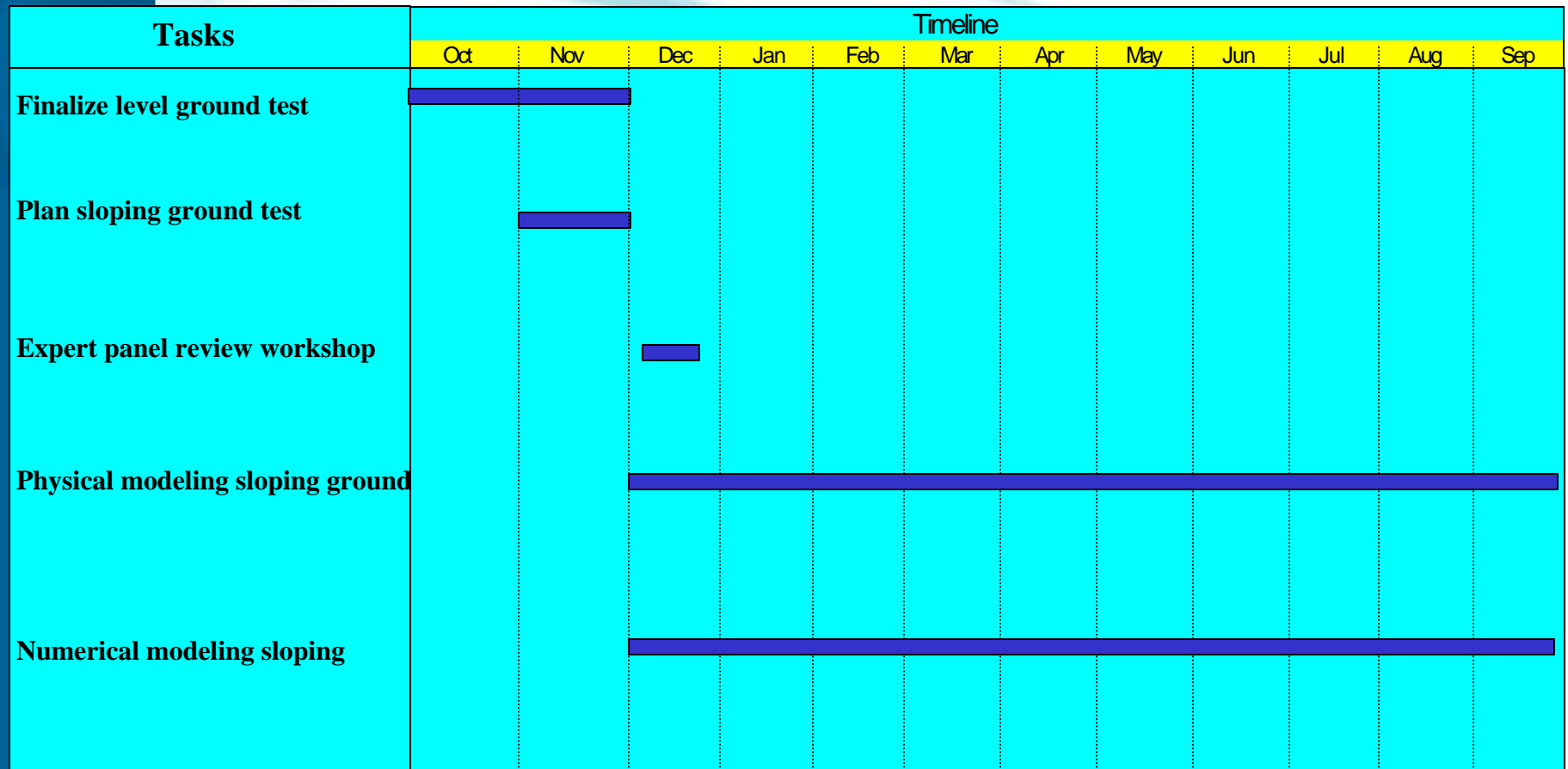
- FY01
 - Address comments from Dec 2000 review panel
 - Conclude level ground testing
 - Document results
- FY02
 - Finalize level ground testing & document
 - Plan & start sloping ground tests
- FY03
 - Conclude sloping ground tests
 - Analyze tests and document results
- FY04
 - Integrate level and sloping ground tests into a final recommended design procedure



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Plan for FY02



 Planned



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Acceptance by Practice

Journal Articles

Submit article to ASCE this July (planned)

Submit article to ASCE NLT December 2001

Submit to International Journal of Physical Modeling, 2001-2002

Conferences (Past)

GeoDenver 2000, ASCE, Proceedings

4th International Conference on Recent Advances..., 2001, Proceedings

UJNR Workshops, 2000

Conferences (Future)

ISSMGE, Turkey, 2001

T2 Committee, Canada, 2002

ECEE, UK, 2002

Workshop for Expert Panel Review

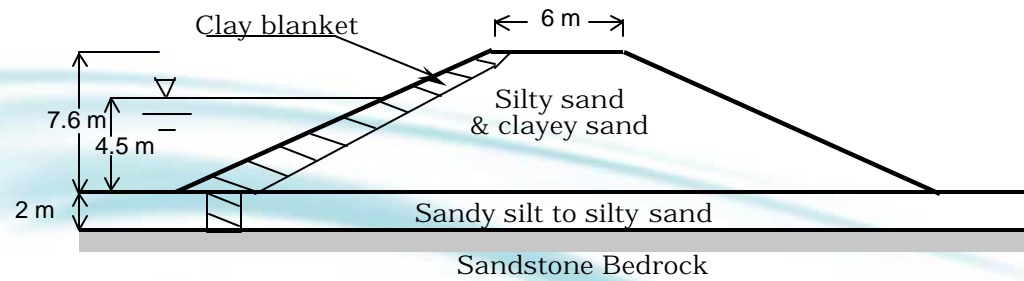
Dec 2000

Dec 2001

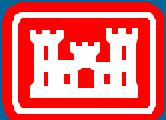


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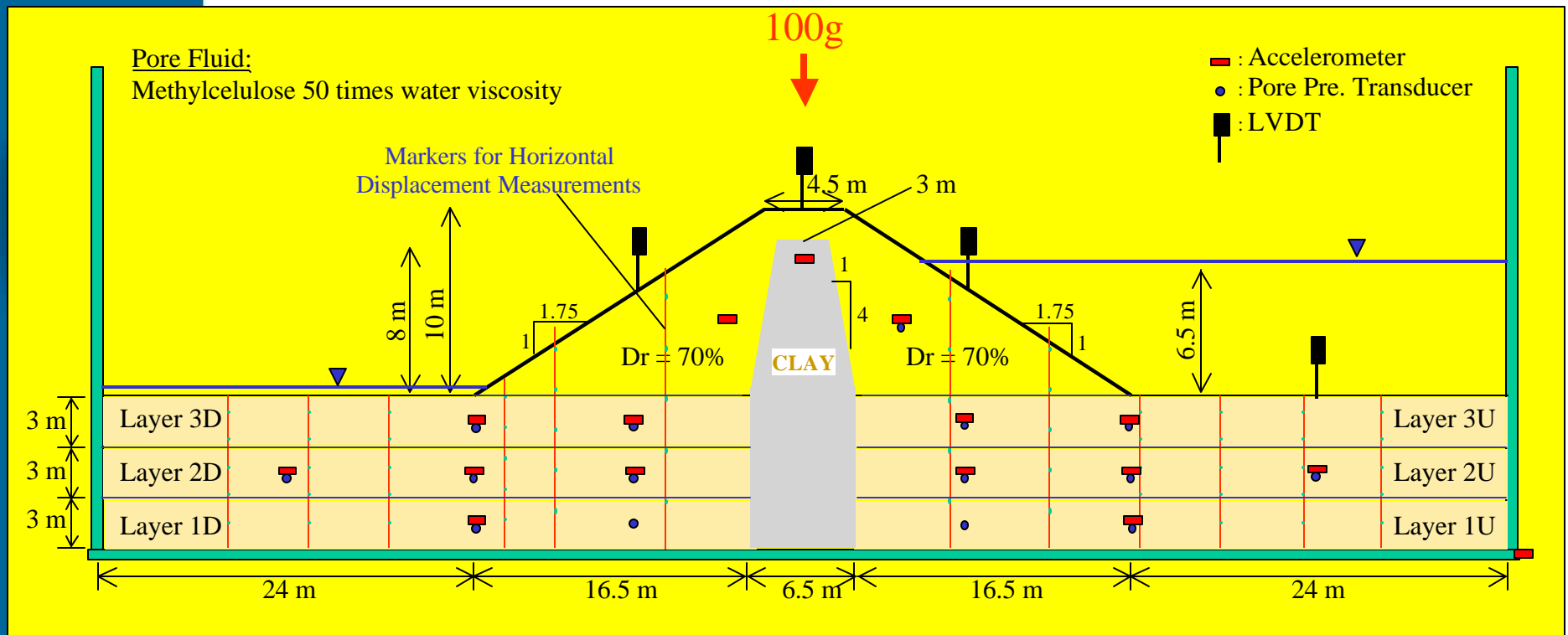


Failure due to Earthquake-Induced Liquefaction in Foundation:
Sheffield Dam during Santa Barbara Earthquake of 1925 (Seed 1970)



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Tests:

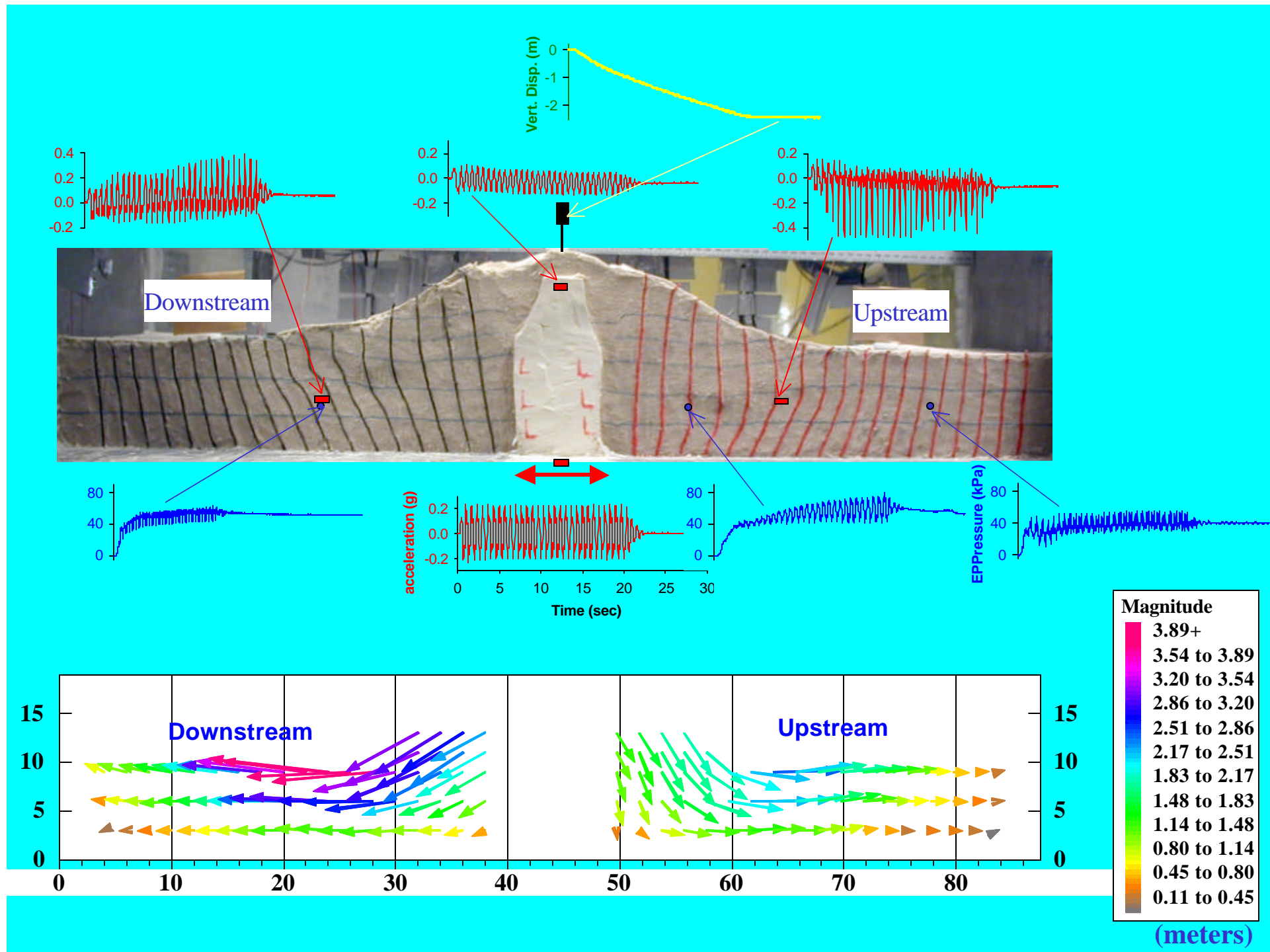
SERIES 1	Vary <i>depth</i> of loose layer in foundation
SERIES 2	Vary <i>thickness</i> of loose layer in foundation
SERIES 3	Vary <i>location</i> of loose layer in foundation

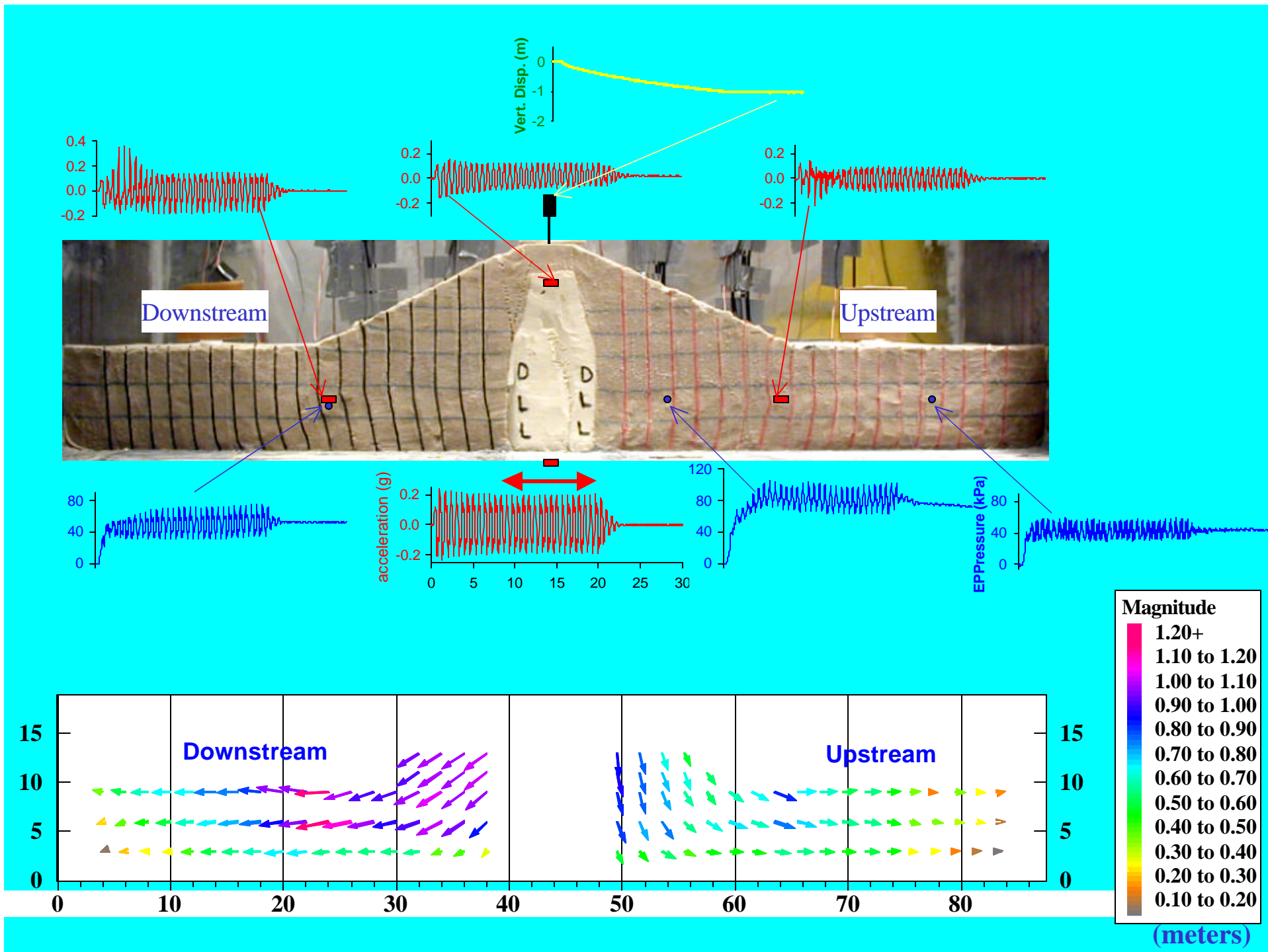
**Loose: Dr=35%,
Dense: Dr= 70%**

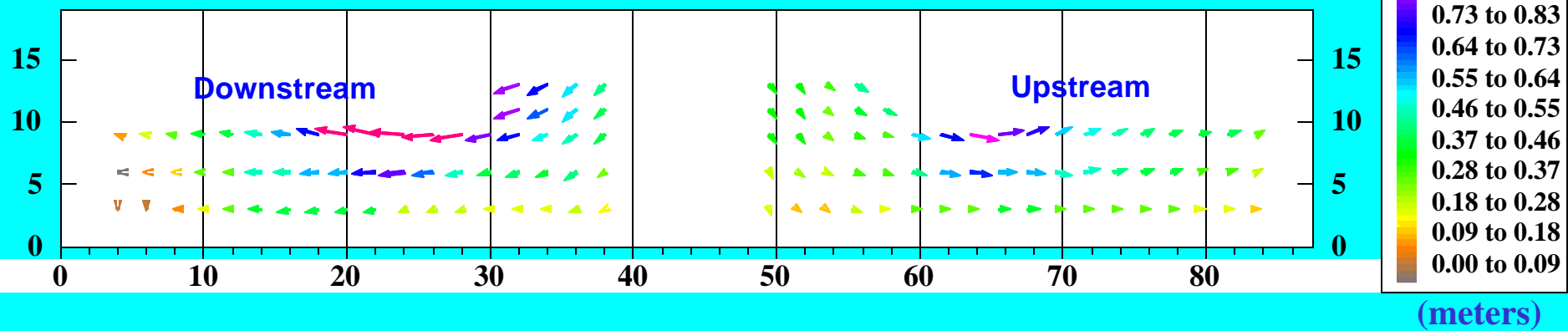
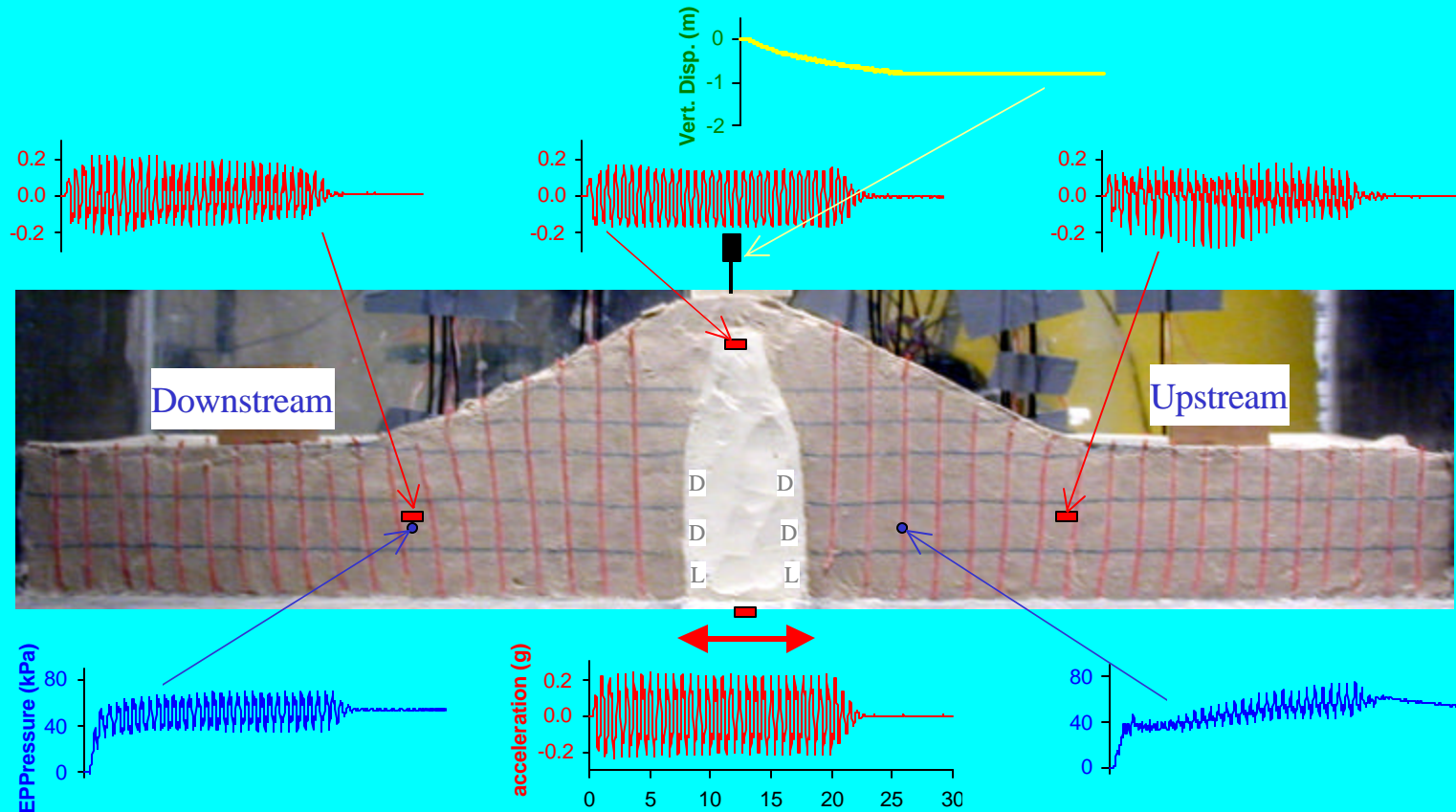


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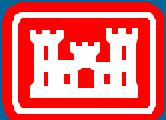
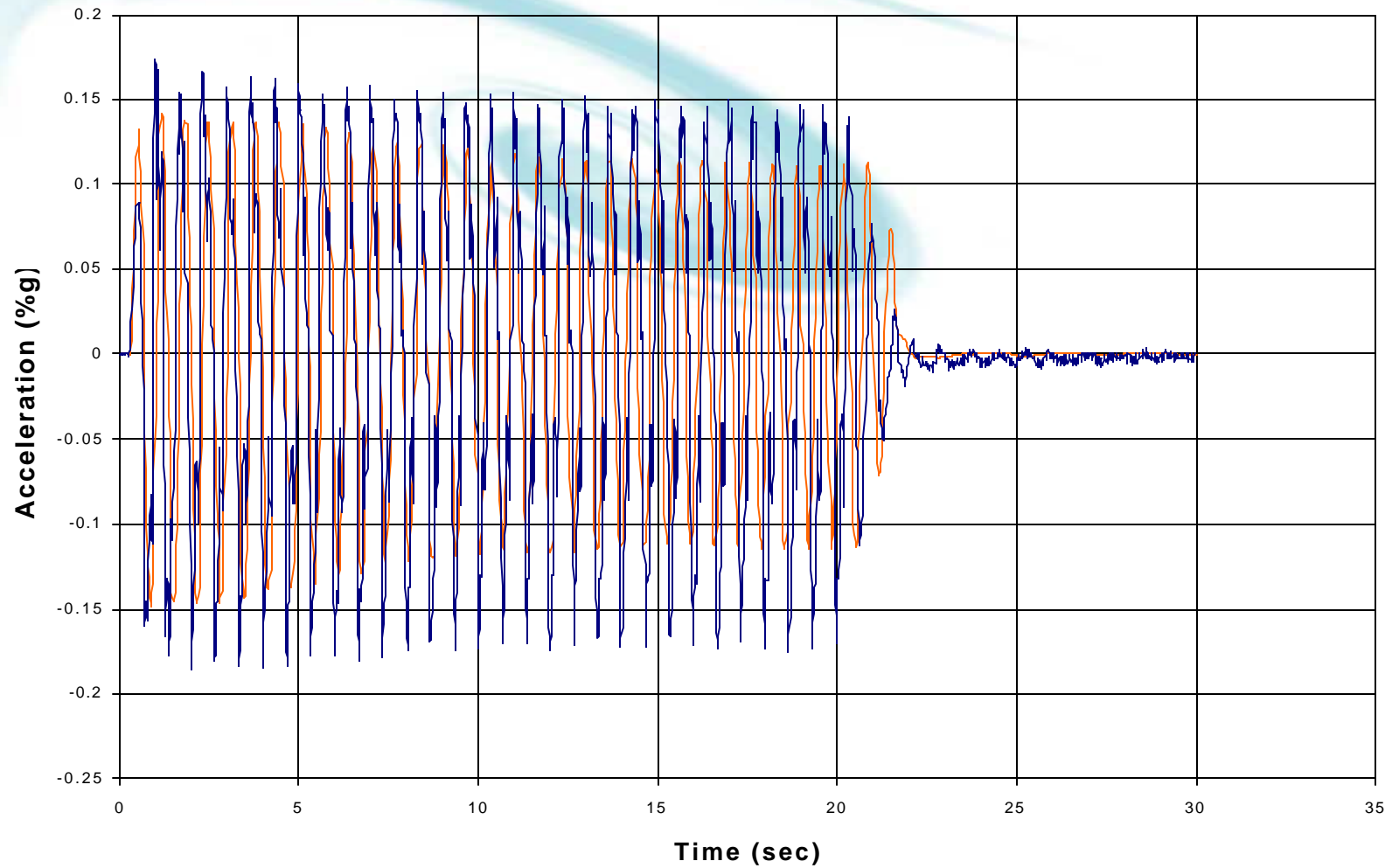
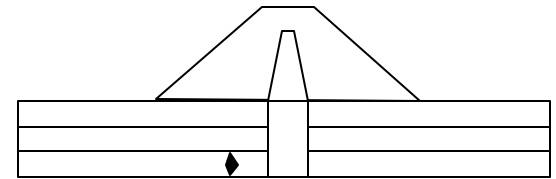
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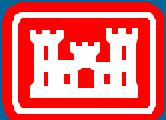
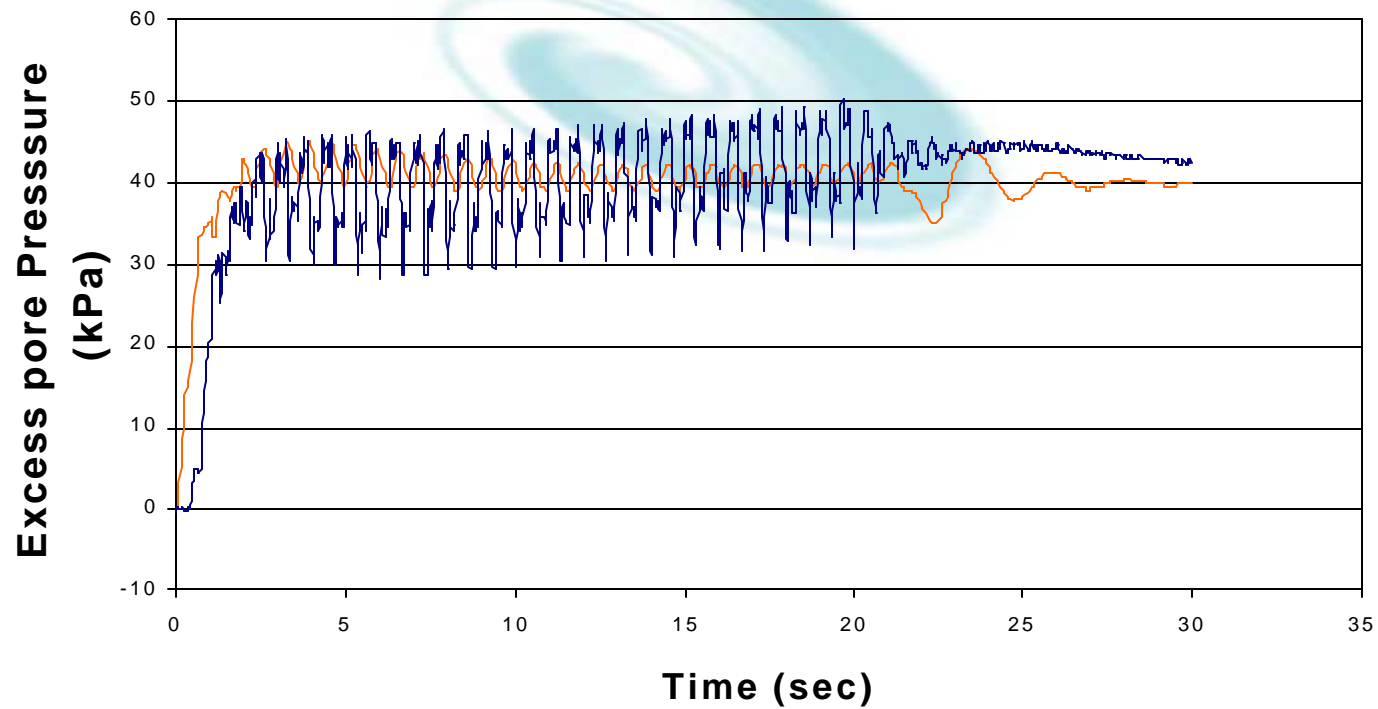
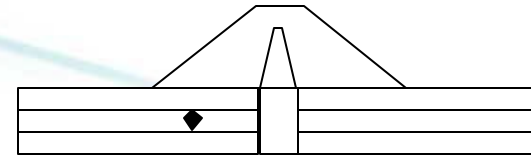
X Nodal Acceleration



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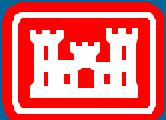
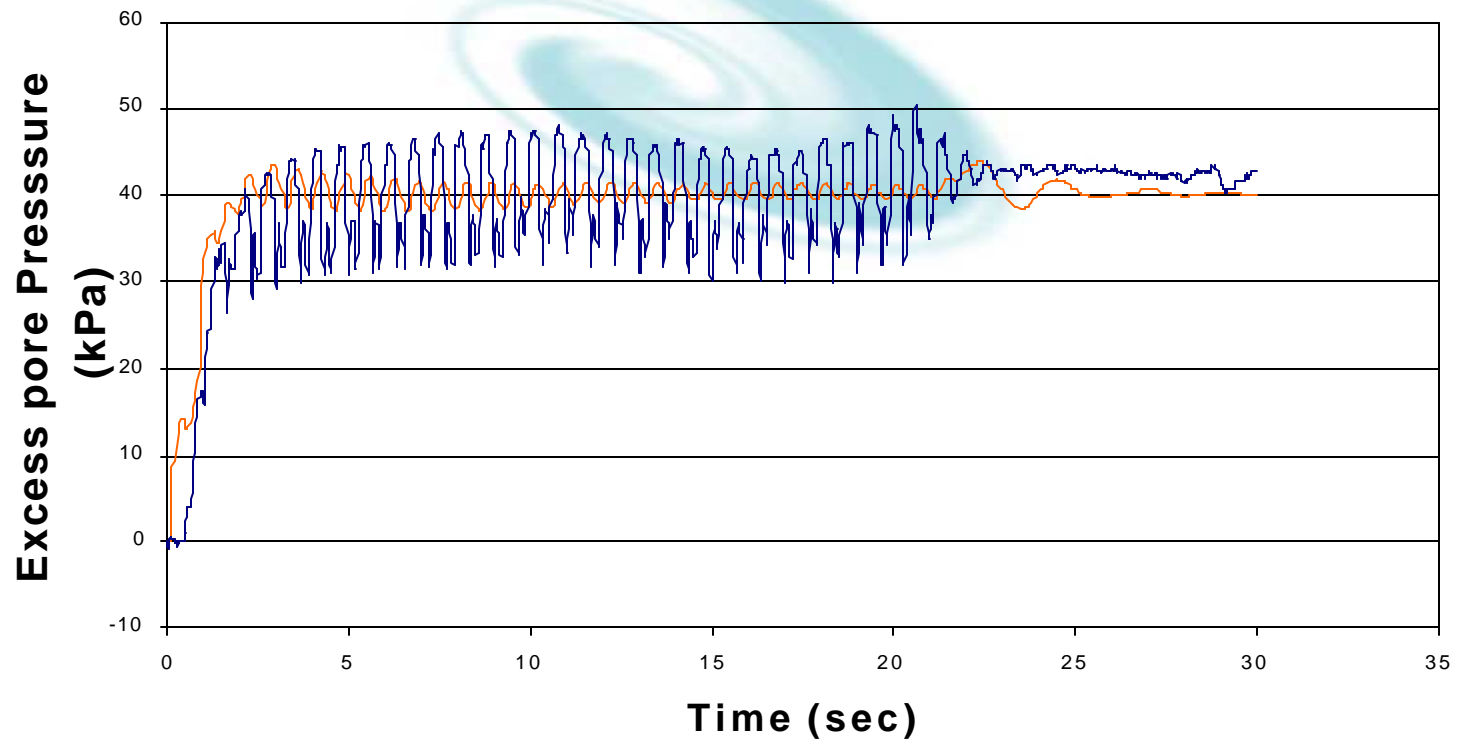
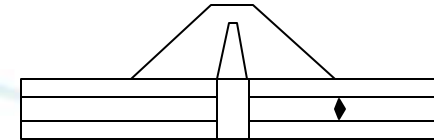
Excess Pore Pressure



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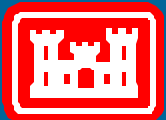
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